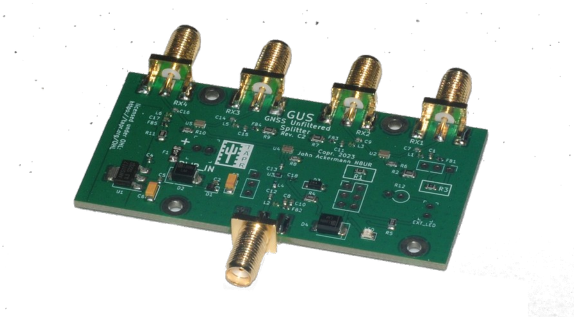
GNSS Unfiltered Splitter ("GUS") Assembly and Operation Manual

GNSS Amplifier and Splitter – Revision D
Revised: 06 July 2023



Introduction

The GNSS Unfiltered Splitter ("GUS") allows up to four GNSS receivers to operate from a single antenna. It includes a low noise amplifier to compensate for loss in the RF splitter network.

Unlike many available GPS/GNSS antenna splitters, the GUS does not provide any RF filtering. This is meant as a Good Thing as it allows the splitter to operate with signals from all GNSS constellations in all three of the currently assigned frequency bands – L1, L2, and L5; in fact, it performs well from below 1000 MHz to at least 1700 MHz. While interference from out-of-band signals can be a problem with GNSS receivers, most antennas include filters and unless you are located near a transmitter site additional filtering is not usually needed. Providing filters that cover all three frequency bands is complex and can be expensive, so by dispensing with them the GUS provides both flexibility and economy.

Another unique feature of the GUS is its flexible DC power input and output configuration. Most GNSS antennas need a DC voltage on their feedline to power the antenna's low noise amplifier, and most GNSS receivers provide power on their antenna outputs to do so. But sometimes the receiver provides a different voltage than the antenna requires, or an external power source is desired for some other reason. Sometimes the antenna output should carry no voltage at all. The GUS provides for many power input and output options. Its default configuration matches the most common case – whatever DC voltage appears at the RX1 port will power the GU and also appear at the ANT port – but jumpers allow other configurations.

An extruded aluminum enclosure with custom end plates is available for the GUS.

NOTE: This manual is for GUS revision D, which started shipping from TAPR after July 6, 2024. The manual for the earlier revision C4 is available at https://web.tapr.org/~n8ur/GUS_Manual_revC4.pdf. The only operational difference in the two versions is the replacement in revision D of the 3.3V fixed voltage regulator with an adjustable one.

Circuit Description

The GUS's RF design is very straightforward. Most of the complexity relates to DC power options.

RF Signal Path

The signal from the antenna enters at J1 and is amplified by U3, an MXDLN14TP low noise amplifier that is designed for mobile positioning devices and has about 18 dB of gain and a 0.6 dB noise figure.[1] The amplified signal goes to hybrid coupler U4, and each of U4's outputs go to another identical coupler, yielding four outputs. The string of couplers reduce the amplitude at each output by a theoretical 6dB, but U3's gain more than makes up for that. The overall gain is about 7 dB ±2 dB.[2]

The GUS uses three 90 degree hybrid couplers in a branch configuration to split the signal, so in theory port is delayed by 90 degrees from the input, port 2 is 90 degrees behind port 1 (as is port 4 relative to port 3), and ports 3 and 4 have an additional 90 degree shift relative to ports 1 and 2. 90 degrees is about 5 cm at 1500 MHz, or 165 picoseconds in free space. The result is phase shifts of 90, 180, 180, and 270 degrees on ports 1 through 4 relative to the input signal. For timekeeping purposes, the relative time delay between channels is usually more important than absolute phase, and the four channel delays are within a few picoseconds of each other.

GNSS splitters that use SAW or other filters typically add significant delay to the signal path – sometimes 20 nanoseconds or more (which is equivalent to 15 feet or so of additional antenna feedline). With its broadband response the GUS has much smaller delay, typically less than 2 ns.

DC Path

A key attribute of the GUS is its very flexible DC power management, which is described in the "Configuration" section below. The default configuration uses 0-ohm resistors R1 and R2 to pass power from the RX1 port to the ANT port and requires setting no jumpers or switches. The GUS itself requires less than 10 ma at 3.3 volts and can operate with power sources from about 2 to 15 volts.

Bias tee networks at the input and each of the four outputs separate the RF and DC paths. As is the case in most GNSS splitters, the default configuration uses DC voltage from the RX1 port to power the LNA, and passes that voltage on to the antenna port. The bias tee networks on ports RX2, RX3, and RX4 provide a 200 ohm DC load, which is required to convince some GNSS modules that they are connected to an antenna.

The various power options will become more clear in the "Configuration" section below.

J1 and J6 route any one of RX1, external DC, or the output of volatage regulator U1 to the amplifier and antenna connector (the "antenna voltage"). U1 is an adjustable AMS1117. If used, J4 allows its input to come from either RX1 or the external power connector. Through-hole resistor R15 to the left of the input connector sets the output voltage based on the formula

$$Vout = 1.25 \times (1+(R15/R14))$$

where R14 is 120 ohms. nstalling 220 ohms at R15 produces about 3.55 volts; 390 ohms produces about 5.3 volts; and 750 ohms produces about 9 volts.

No matter the power source, Zener diode D3 and resistors R3/R4 limit the voltage reaching LNA U3 to 3.6 volts (the LNA is specified to operate from 1.6 to an absolute maximum of 4 volts). With antenna voltage at 3.3, it sees about 2.8 volts, which is its nominal operating voltage.

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1 By the way, this is the tiniest IC I've ever worked with – 1.1 x 0.7 mm!

2 RF performance depends on the load at the other receiver outputs. Unless noted otherwise, all measurements in this document were made with 50 ohm loads on the unterminated ports.

R3 and R4 are each rated at 125 mw. As the antenna voltage increases, R3 and R4 will drop more voltage and dissipate more heat. Their combined rating is 250 mw. At 9 volts, they dissipate 145 mw so are operating safely, though they will get warm. Since virtually no GNSS antennas require more than 9 volts, we recommend not setting the antenna voltage higher than that.

R1 and R13 are zero ohm resistors that by default bypass J1, J4, and 6 to provide the most common configuration of RX1 power fed directly to the LNA and antenna. Removing them allows custom power routing.[3] If R1 is removed, pins 2 and 3 of J1 should be closed, which will place a 200 ohm DC load on RX1, as is done on the other RX ports. That fools the receiver into thinking it has an antenna connected; some receivers issue an alarm if they don't see any current draw.

Diodes D1, D2, and D4 all provide protection against transients and reverse polarity.

PCB jumper JP1 ("ANT_PWR_ENA") can be cut to remove any DC voltage from the antenna input connector. Doing so allows a filter or attenuator to be used ahead of the GUS.

PCB jumper JP2 (LNA_ENA") can be cut to disable the on-board LED to reduce power consumption.

J13 ("EXT_LED") can be used to power an external LED in which case user-installed R12 ("EXT_LED RESISTOR") provides its current limiting. The external LED is not affected by the setting of JP2.

3Note that after removing R1 or R13, original operation can be restored via the jumpers, so there's no need to resolder those tiny components. Just knock them off the board with a soldering iron.

Typical Performance

The overall gain of the GUS varies from about 6 dB to a bit over 9 dB at the 3 L-band GNSS frequencies across the four output channels. The noise figure is below 1.5 dB.[4]

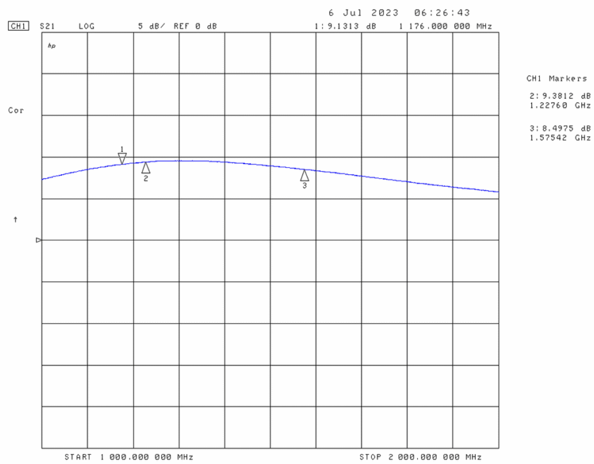


Figure 1: RX Port 1 Gain

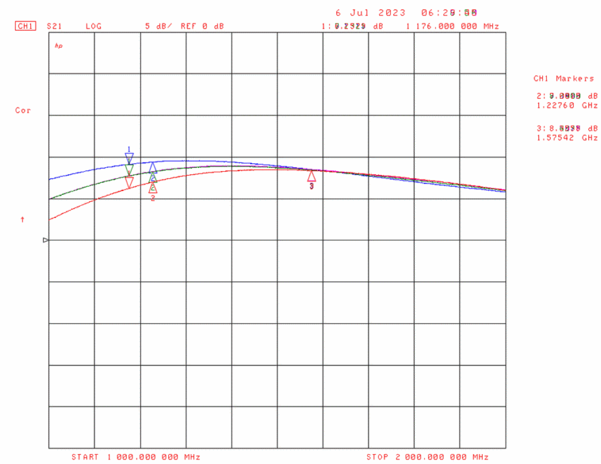


Figure 2: Gain of All Four Ports

Figure 1 shows the gain from antenna input to receiver port 1 output, and figure 2 shows the four ports simultaneously. In revision C4 we noticed that the gain of port 3 at the L5 frequency (1176 MHz) was about 2 dB below the other ports. In revision D some of the RF traces were changed in an attempt to address this. Figure 2 shows that there is still a spread of about 3 dB, but now port 4 has the lowest amplitude. The other ports were tightly grouped befpre, but now ports 2 and 3 are between ports 1 and 4. Note that at L1 (1575 MHz), the most commonly used frequency, the four ports have almost identical gain.

The return loss of the antenna port ranges from about 4 dB at 1176 MHz to 12 dB at 1575 MHz.[5] The return loss of the receiver ports is 20 dB or greater on all four ports at all three frequencies. Port-to-port isolation is at least 18 dB at all frequencies.

In virtually all these measurements, performance at the highest frequency, L1, is better than at the lower L2 and L5. The hybrid couplers used as splitters are usable from 1000 MHz, but are optimized for the 1700 – 2000 MHz frequency range. At lower frequencies their amplitude balance and isolation are reduced.

4 This is not as good as the specification for the LNA by itself, but includes the real-world losses of the input network. It was measured at port 1 with an HP 8970B /436A noise figure meter.

5 This is not all that good, but since the input impedance of the antenna amplifier is unknown, its effect is hard to estimate. Because the GUS has ample excess gain, a 6 dB attenuator at the antenna input would improve the match and could avoid possible signal overload at the receiver. Remember that there is DC on the antenna input, and the attenuator will shunt that to ground. Opening the LNA_PWR_ENA jumper will prevent this, but then the antenna will need power from another source.

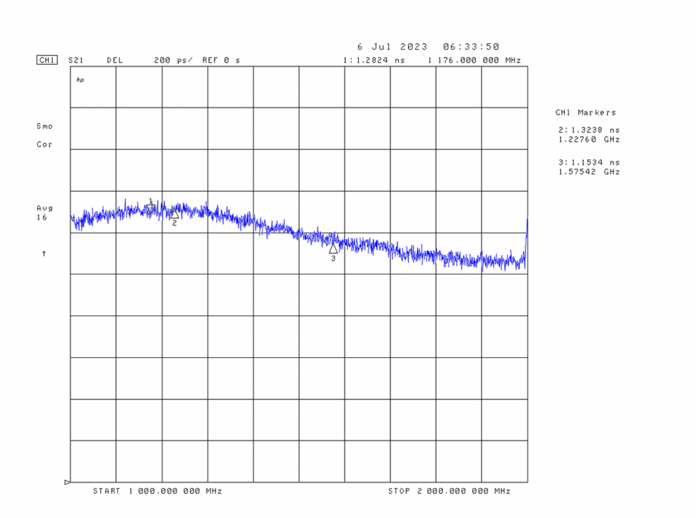


Figure 3: RX Port 1 Group Delay

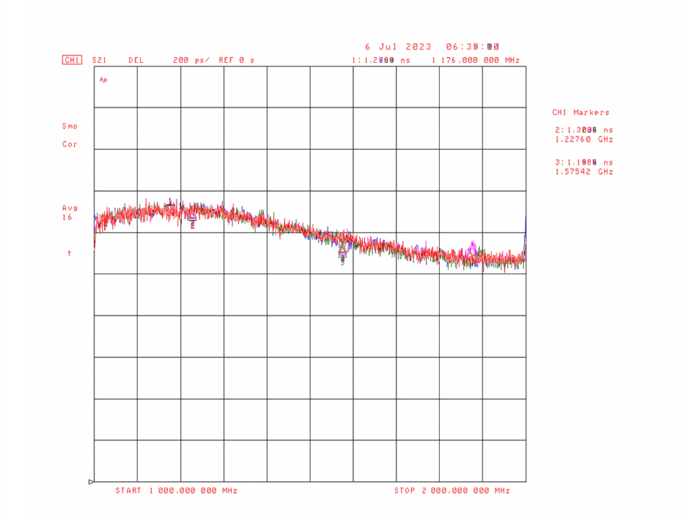


Figure 4: Group Delay of All Four Ports

The propagation delay through all four channels is virtually identical: about 1.28 nanoseconds at L5, 1.31 ns at L2, and 1.16 ns at L5. Because there is no filtering to introduce additional delays, the GUS adds very little electrical length to the cable.

Assembly

Minimal assembly requires only soldering the SMA connectors which mount on the edge of the PC board. Solder all the ground pins of each connector, on both the top and bottom of the board. If you plan to use an enclosure, be sure the connectors are installed straight and flush against the circuit board.

For operation with a power source other than the receiver at port 1, use a soldering iron to remove resistors R1 and R13 (each surrounded by a white box on the silkscreen) off the board. You can use the iron to heat both sides at once and knock them off the board, as the original configuration can be reset later via the jumpers. Headers with jumper blocks can be installed at J1, J5, and J7, or you can simply solder wires across the appropriate pins.

If using the on-board voltage regulator, install a resistor for the appropriate output voltage at R15 (vertically mounted through-hole). 220 ohms gives about 3.55 volts, 390 ohms gives about 5.4 volts, and 750 ohms gives about 9.0 volts.

The GUS PC board slides into the second slot above the bottom "shelf" which sits above the removable plate in the enclosure – in orther words, the removable plate is on the bottom). Use the provided screws to secure the front and rear panels to the extrusion, and the washers and nuts to secure the SMAs. The front and rear panel have copper beneath the solder mask and will provide conductivity with the extrusion and possibly some shielding.

Configuration

In many cases the GUS will require no configuration at all. If the GNSS receiver connected to port 1 provides the voltage required for the antenna's LNA, nothing further need be done. When other power configuration is required, the GUS is very flexible. The table below shows some of the power possibilities and how to enable them.

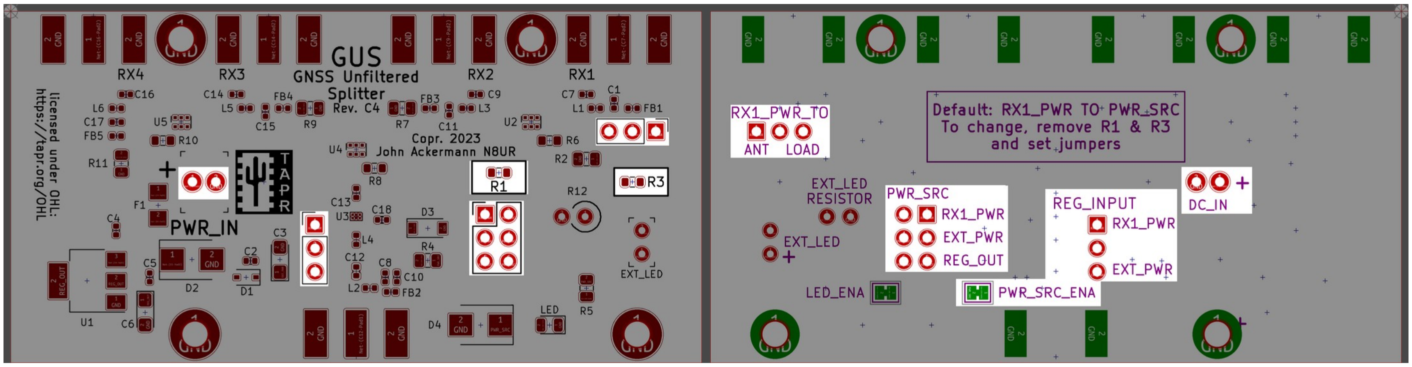


Figure 5: Gus Power Configuration Top (left) and Bottom (right)

RX1 direct to ANT (default)	R1 and R13 in place	<u>OR</u>: **RX1_PWR_TO** to **ANT** **PWR_SRC** to **RX1_PWR** **REG_INPUT** open
RX1 through regulator to ANT	R1 removed, R13 in place; install appropriate resistor at R15	<u>AND</u>: **PWR_SRC** to **REG_OUT** **REG_INPUT** to **RX1_PWR**
External DC direct to ANT	R1 and R13 removed	<u>AND</u>: **RX1_PWR_TO** to **LOAD** **PWR_SRC** to **EXT_PWR**
External DC through regulator to ANT	R1 and R13 removed; install appropriate resistor at R15	<u>AND</u>: **RX1_PWR_TO** to **LOAD** **PWR_SRC** to **REG_OUT** **REG_INPUT** to **EXT_PWR**
Power to LNA; no power to ANT	Any of above	Any of above <u>AND</u>: **PWR_SRC_ENA** opened

R13 does not enter into the DC power routing as such, but if you are using external power you should remove it and jumper the center of J5 to the "LOAD" pin. That will prevent external power from back-feeding (and possibly damaging) the receiver and will provide a DC load to make the receiver think it has an antenna connected; some applications test for current to determine the antenna is present and working.

To open the PWR_SRC_ENA jumper, use a hobby knife to remove the trace between the two pads. Operation may be restored later by putting a solder blob across the pads. If your antenna can get power from another source (like another splitter ahead of the GUS, or a separate voltage injector), opening the PWR_SRC_ENA jumper permits placing an attenuator or filter at the GUS input without the risk of shorting power to ground via a DC path in the external device.

Do not apply external power without first removing R1 and/or R13 and setting the appropriate jumpers as directed in the table. Improper configuration could damage the GNSS receiver, and possibly the GUS itself.

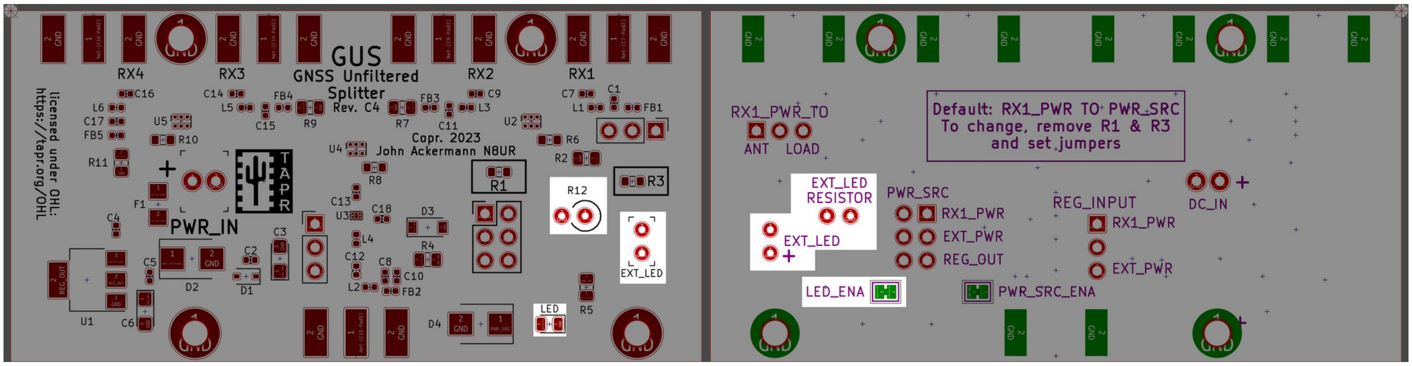
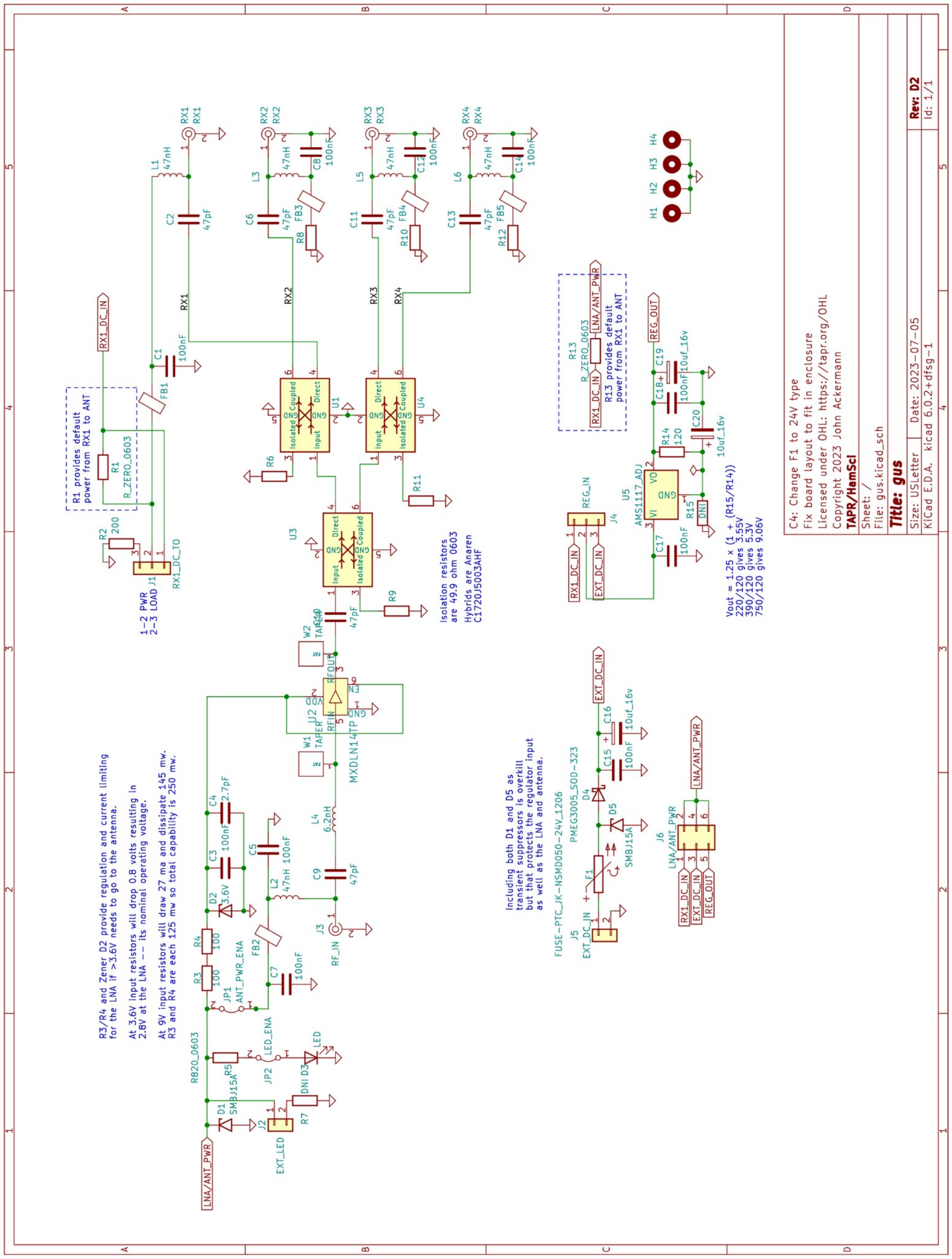


Figure 6:Gus LED Configuration Top (left) and Bottom (right)

Figure 5 shows LED configuration options. By default, the on-board LED will illuminate when power is present. To disable the LED, open PCB jumper LED_ENA. You can use a hobby knife to remove the trace between the two pads; to restore operation later, put a solder blob across the bads.

An external LED can be attached at the EXT_LED pads. In that case, install an appropriate current limiting resistor at R7. The LED_ENA jumper does not affect operation of the external LED.

Schematic


R1 provides default power from RX1 to ANT
1-2 PWR
2-3 LOAD
Isolation resistors are 49.9 ohm 0603
Hybrids are Anaren C1720J5003AHF
R13 provides default power from RX1 to ANT
Vout = 1.25 x (1 + (R15/R14))
220/120 gives 3.55V
390/120 gives 5.3V
750/120 gives 9.06V
R3/R4 and Zener D2 provide regulation and current limiting for the LNA if >3.6V needs to go to the antenna.
At 3.6V input resistors will drop 0.8 volts resulting in 2.8V at the LNA -- its nominal operating voltage.
At 9V input resistors will draw 27 ma and dissipate 145 mw. R3 and R4 are each 125 mw so total capability is 250 mw.
Including both D1 and D5 as transient suppressors is overkill but that protects the regulator input as well as the LNA and antenna.
C4: Change F1 to 24V type
Fix board layout to fit in enclosure
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Sheet: /
File: gus.kicad_sch
Title: gus
Size: USLetter
Date: 2023-07-05
KiCad E.D.A. kicad 6.0.2+dfsg-1
Rev: D2
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